SEGREGATION-BAND DYNAMICS IN PARTICLE-LADEN RIMMING FLOW

Peter J. Thomas[1] & Estelle Guyez[2]
[1] *Fluid Dynamics Research Centre, School of Engineering, Coventry CV4 7AL, UK.*
[2] *CEA DEN/DTN/SE2T/LITA, 17 rue des Martyrs, 38000 Grenoble, France.*

Rimming flow is the flow established inside a partially fluid-filled cylinder when it is rotated about a horizontal axis of rotation. While the cylinder is stationary the liquid rests in a quiescent pool within the cylinder. When the cylinder rotates the rising side of its inner surface drags out a film of liquid from the pool which then coats the inner cylinder wall above the pool. Rimming flow of homogeneous liquids can display a number of different, distinct flow states and it has been the subject of numerous studies in the past [1, 2].

In Refs. [3, 4] we investigated for the first time how the flow patterns of rimming flow are modified when successively increasing amounts of small particles are added to the liquid. During these experiments we observed that, soon after the cylinder begins to rotate, the particles segregate from the liquid and establish the new type of banding pattern shown in figure 1. The banding structure consists of a regular pattern of circumferential regions with, alternatingly, high particle concentrations and regions of very low particle concentrations - sometimes entirely free of particles. Our long-term observations, some lasting over four weeks, revealed that the banding pattern can drift very slowly along the axis of rotation revealing complex spatiotemporal behaviour [5, 6]. Here we summarize and discuss some of our recent work investigating the details of the band-drift dynamics.

Figure 2 displays examples of spatiotemporal diagrams illustrating typical aspects of the system dynamics in different regions of parameter space. The diagrams were constructed by analysing sequences of photographs of the type shown in figure 1. From each photograph of a sequence a pixel line was extracted horizontally across the cylinder (*c.f.* figure 1). The extracted lines were processed to display black at positions where a band is present and white for regions of low particle concentrations. The sequence of successive pixel-scan lines of each experiment were then composed into the spatiotemporal plots of figure 2.

Figure 2(a) shows results for an experiment in which the segregation bands drifted from positions 0 cm $< L <$ 13.5 cm towards the left end wall ($L = 0$ cm) and from positions 13.5 cm $< L <$ 27 cm towards the right end wall ($L = 27$ cm). The left-hand ordinate displays time t in terms of cylinder rotations t/T (T, cylinder rotation period) and the right-hand ordinate additionally shows time in terms of days. The figure reveals that it took the band initially located near $L \approx 12$ cm at $t/T = 0$ about 3000 cylinder rotations (0.5 days), to drift to the left endwall at $L = 0$ cm. In the experiments that resulted in figure 2(b) the drift direction is reversed and the bands drift from both endwalls towards the centre of the cylinder. Note the extremely slow drift velocities of the order of approximately 13.5 cm/25 days. Figure 2(c) displays data from an experiment with zig-zag band drift in the centre of the cylinder and band drift similar to that of figure 2(a) in the regions adjacent to the left and right endwall. For the experiment in figure 2(d) all bands initially drifted towards the endwalls for about 0.4 days. However, thereafter the system dynamics suddenly changed with the centrals bands becoming stationary while only the outermost bands continued to drift towards the endwalls. We have observed various other distinct drift modes extending from completely stationary banding structures, over other complex geometric patterns to entirely irregular band-drift patterns. We will consider for which conditions in parameter space the different band-drift modes are adopted and we will discuss the governing non-dimensional groups responsible for the drift-mode selection.

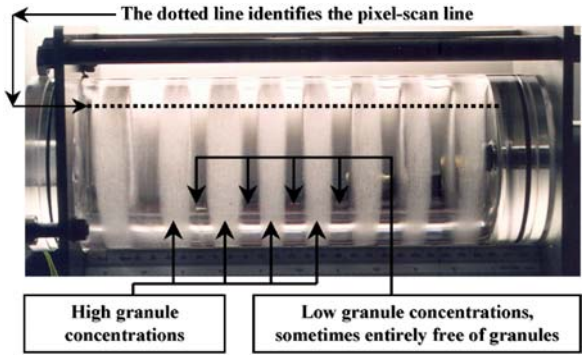

Figure 1: Head-on view of segregation-band pattern in partially fluid-filled, horizontally rotating circular cylinder (cylinder length, 27 cm; diameter, 10 cm).

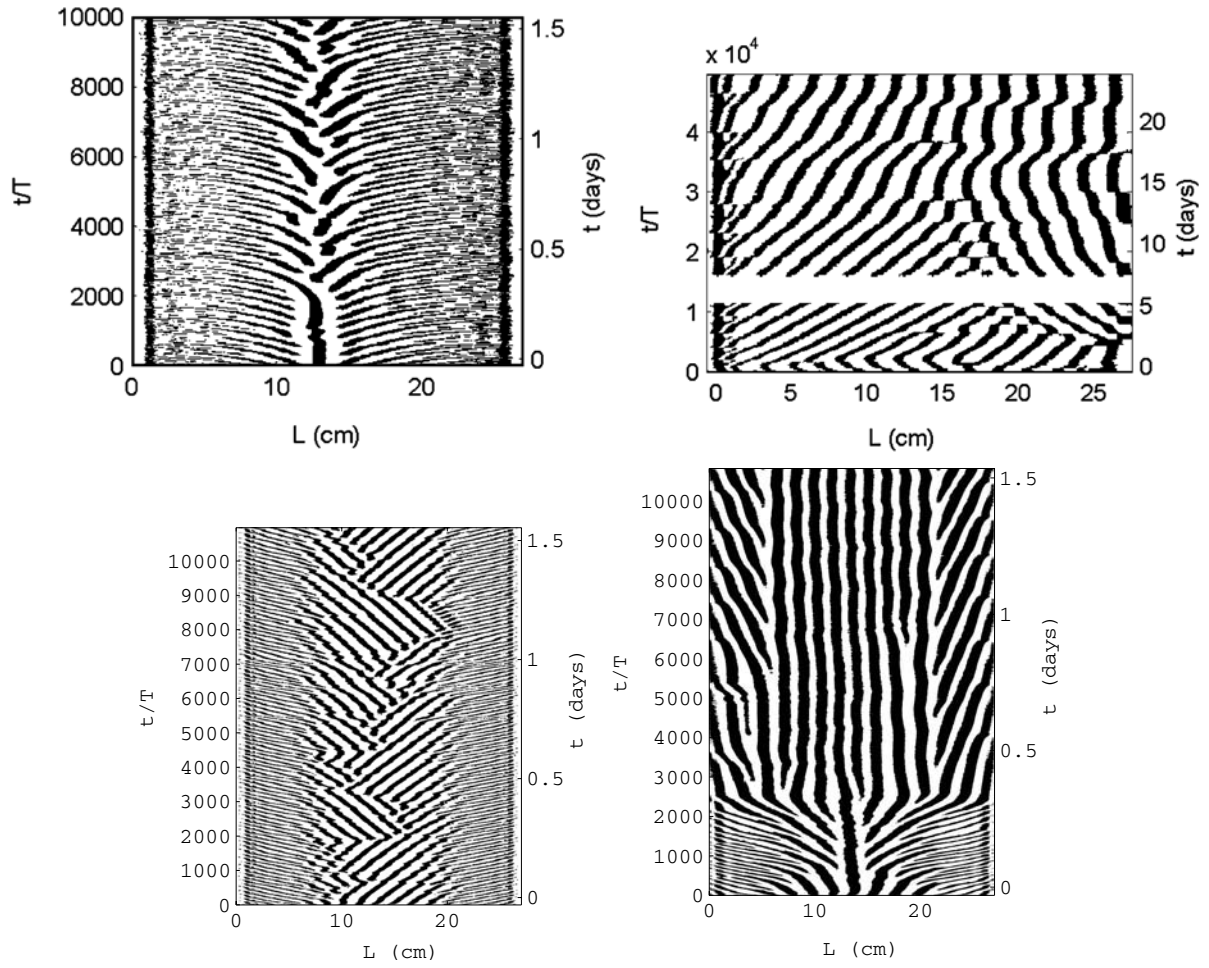

Figure 2: Spatiotemporal diagrams illustrating some typical drift modes of the segregation bands.

References

[1] S. T. Thoroddsen & L. Mahadevan, Experimental study of coating flows in a partially-filled horizontally rotating cylinder. *Exp. Fluids* **23**, 1–13 (1997).

[2] G. Seiden & P. J. Thomas, Complexity, segregation and pattern formation in rotating-drum flows. Submitted to *Rev. Mod. Phys.* (2011).

[3] O. A. M. Boote & P. J. Thomas, Effects of granular additives on transition boundaries between flow states of rimming flow. *Phys. Fluids* **11**, 2020–2029 (1999).

[4] P. J. Thomas, G. D. Riddell, S. Kooner & G. P. King, Fine structure of granular banding in two-phase rimming flow. *Phys. Fluids* **13**, 2720–2723 (2001).

[5] E. Guyez & P. J. Thomas, Spatiotemporal segregation-pattern drift in particle-laden rimming flow. *Phys. Rev. Lett.* **100**, 075401 (2008).

[6] E. Guyez & P. J. Thomas, Effects of particle properties on segregation-band drift in particle-laden rimming flow. *Phys. Fluids* **21**, 033301 (2009).